Ludwig Boltzmann (1844 – 1906)

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Ludwig Boltzmann, Austrian physicist; devoted the second part of his life to philosophy. His natural philosophy is of great importance in the fields of philosophy of science and contemporary philosophy. This article presents (a) his biography; (b) different aspects of his natural philosophy; and (c) bibliography of his philosophical works and the works devoted to his natural philosophy.

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Biography

To understand who was Ludwig Boltzmann, it is useful to note two descriptions reported at the beginning of Broda's famous book, Ludwig Boltzmann: *Man, Physicist, Philosopher*. *(i)* In J. Bronowski's electric view of human thought *The Ascent of Man*, Ludwig Boltzmann is praised in the following words: "And yet one man, at the critical turn of the century, stood up for the reality of atoms on fundamental grounds of theory. He was Ludwig Boltzmann, at whose memorial I pay homage. Boltzmann was irascible, extraordinary, difficult man, an early follower of Darwin, quarrelsome and delightful, and everything that a human being should be." *(ii)* Paul Feyerabend notes in the Encyclopedia of Philosophy: "In his realization of the hypothetical character of all our knowledge, Boltzmann was far ahead of his time and perhaps even our time.

Ludwig Eduard Boltzmann was born February 20, 1844 in a house on the main street of the Landstrasse district of Vienna. His father was an Imperial and Royal Cameral-Concipist, a tax official, and his mother, Katharina Pauernfeind, was from Slzburg. From childhood he lived in security and material comfort. He received his preliminary education from a private tutor in the house of his parents. At the age of 15 he lost his father. He was very industrious and with the exception of one term, he always was the best in his class.

In 1863 he entered to the University of Vienna to study physics, and received his doctorate in 1866, and gave his inaugural address as Privatdozent (lecturer) in 1867. At the age of 25, he became full professor of mathematical physics at the University of Graz in the province of Styria. In 1873 he returned to the University of Vienna as professor of mathematics. On the 17th day of July 1876, Ludwig Boltzmann married Henriette von Aigentler, an attractive lady with long fair hair and blue eyes from Graz. Boltzmann spent 14 happy years in Graz, and during this time developed his ideas on the statistical concept of nature.

He was honored by the academic community and by the government. In 1878 he became dean of the faculty, in 1881 Regierungsrat, in 1885 member of the Imperial Academy of Sciences, in 1887 president of the University of Graz, and in 1889 wirklicher Hofrat. In 1890 he accepted the chair of theoretical physics at the University of Munich. After death of his professor, Josef Stefan (1835 – 1893), he because his successor at Vienna University in 1894. However, it was difficult for Boltzmann to find a nice group of friends and colleagues as he had in Munich; particularly when Ernst Mach (1838 – 1916), successful experimentalist in physics and sense physiology, critical historian of physics, adversary of atomism, positivist philosopher, became professor of philosophy and history of sciences in 1895. Thus, Boltzmann accepted an appointment as professor of theoretical physics in Leipzig. After retirement of Mach due to bad health, Boltzmann returned to Vienna in fall 1902.

In addition to his teaching materials of theoretical physics, he started to lecture on philosophy in 1903. Indeed, he taught a university course namely "Methods and General Theory of the Natural Sciences" on the chair of natural philosophy, previously occupied by Ernst Mach for a course namely "History and Theory of the Inductive Sciences".

The lectures of Boltzmann on natural philosophy were very popular and had achieved a considerable attention at that time. His first lecture was an enormous success. Even though the largest lecture hall had been chosen for it, the people stood all the way down the staircase. Students, assistants, professors, ladies had come. The hall was ornated with twigs of silver fires and he received enthusiastic ovations. All the newspapers reported about this event. His mail was full of letters of consent. He even had an audience with Emperor Franz Joseph. The Emperor told Boltzmann that he was glad about his return and that he had heard how crowded his lectures were.

In the last years of his life, Boltzmann was in bad attitude of heath. His health had suffered from the constant dispute with his scientific opponents. His eyes had deteriorated to an extent that he had trouble reading. He had to employ a woman who read scientific articles to him and his wife wrote his manuscripts. In addition, he suffered from strong asthma attacks at night and presumably from angina pectoris. Furthermore, he was plagued by heavy headaches due to overwork. However, Boltzmann had never given any consideration to his health but sacrificed it to his scientific work.

Despite his great success work, his enjoyment of the beauties of nature and art in full measure, and his optimism and humor, he suffered from depressions. Thus, even in company he would sometimes lapse into long dismal silences that could hardly be broken. Boltzmann himself remarked in jest on his sixteenth birthday that this quick transitions from cheerfulness to sadness stemmed from the fact that he was born in the night between Carnival Tuesday and Ash Wednesday aimed the dying noises of the dance. Boltzmann was subject to severe asthma attacks and suffered great pain. It has been reported that he feared loss of his creativity and may have been overburdened by work. Tragically, while on a summer vacation at Duino near Trieste he committed suicide during an attack of depression.

Ludwig Boltzmann, one of the greatest thinkers of all nations and all times dies on September 5, 1906. On September 8, a splendid memorial ceremony was held for him, and many outstanding scientists of the time attended and contributed. Boltzmann's early death is all the sadder because he himself expressed lively regret that death would prevent him from witnessing the further development of science. Boltzmann's grave of honor in Central Cemetery in Vienna was taken into the guardianship of the municipality of Vienna by alderman Julius Tandler in 1933: "The city of Vienna and its people are proud of the man of genius who lived here, and they have endeavored to find a burial place worthy of him". The grave has a beautiful white marble bust of Boltzmann, created by Gustinus Ambrosi. Into the monument the equation is inscribed that will retain its validity after all the grave stones have sunk under the dust of the centuries, as Hans Thirring put it at the unveiling. The short and simple equation that expressed Boltzmann's greatest scientific achievement is: $S = k \log w$.

Personality

Usually, it is very useful to know personality of a person to understand his philosophical view. At least, this factor is of particular interest for Boltzmann due to its interesting personality. E. Broda, Boltzmann biographer, in his famous book "*Ludwig Boltzmann: Man, Physicist, Philosopher*" shows that personality of Boltzmann as a great man is of interest as its greatness in physics and philosophy.

In the historical reports, everyone who knew Boltzmann has declared that Boltzmann was a great man due to his pretty personality. In spite of many scientific and philosophical controversies, he had a good relationship with his opponents. Despite he always had scientific and philosophical antagonism to Wilhelm Ostwald (1853 – 1932), they were good personal friends. For instance, Boltzmann went to Leipzig in 1900 based on an invitation of Ostwald. Even against Ernst Mach which he had a bad attitude, as he even left his beloved Vienna in 1900 due to the existence of Mach there; they were very polite in respect with each other. Indeed, one of the important reasons raised in his critique against Schopenhauer is impolite terminology of Schopenhauer against other philosophers, as he states it is not appropriate for a great thinker.

He was a true patriot and did indeed love his native Austria. In spite of the political conditions that existed in Austria, he loved to live in his homeland. In a letter he wrote to Josef Loschmidt (1821 – 1895), his old colleague, in 1892, he says: "I must report as the first item of news that I am still living but to be sure no better here than in my beloved Austria." He expected a better atmosphere for scientific activities in Leipzig, but he did not feel at all comfortable there.

The interesting feature of Boltzmann's patriotism was his philanthropic and intellectual view, rather than common mindless fanaticism. Boltzmann expressed his critical patriotism, referring to the lost war against Prussia: "Two years ago, when I spoke about the year of misfortune, 1866, at a party in Oxford, one of those present thought he would pay me compliment by saying the Austrians were too good to be victorious. We shall have to rid ourselves of this goodness and self-contentment. But since today modesty and frugality are disappearing more and more from the world, we must congratulate ourselves on the fact that precisely Austria has today, as always, men whose only vice is an excess of these virtues. Let us call out with Mozart [in the "magic Flute"], our paragon of moderation and serenity: Within our holy walls, Where people love each other, No traitor can lurk, Because we forgive the enemy. Those who are not pleased by such teachings and the example of such men do not deserve to be human, do not deserve to be Austrian." His condemnation of nationalist student riots at the University of Vienna to prevent the reconciliation with Czech sought by the Orime Minister, Count Badeni is worth noting. In fact, such nationalist troubles were one of the main reasons for his departure to Leipzig.

Boltzmann was an excellent teacher. His lectures were described as "crystal clear". According to Stefen Meyer, "seldom was such outstanding teaching ability coupled with such extensive knowledge." As Ludwig Flamm stated, "Boltzmann's mode of expression was lively, clear and fascinating, witty and humorous, and often accompanied by stimulating anecdotes." Boltzmann did not shrink at all from correcting himself during the lecture with the words, "Ach, that was stupid of me!".

Boltzmann had a great interest in communications with others and was also high-spirited in discussion. The President of the Accademia dei Lincei in Italy called Boltzmann in his obituary 'a most remarkable polemist, much feared in congresses'. Arnold Sommerfeld described Boltzmann's entry into the dramatic discussion on energism at the conference of German naturalists at Lubeck in 1895: "Helm (Dresden) was the main speaker on behalf of energism; backing him was Wilhelm Ostwald, and backing both of them was the natural philosophy of the absent Ernst Mach. The opponent was Boltzmann, seconded by Felix Klein. The battle between Boltzmann and Ostwald was both outwardly and inwardly like a bull fighting against the flexible fencer. But this time the bull conquered in spite of all the torero's fighting skill. Boltzmann's arguments triumphed. All of us younger mathematicians were on Boltzmann's side …"

He indeed did not in the least deny the importance of objections to his theories, but he welcomed them. He appreciated the discussions which gave him the opportunity of working out the basis of all his works with more precision. For instance, although Boltzmann never agreed with Zermelo and always called him "the rogue", He was glad that his statistical approach has achieved attention in German-speaking countries.

Boltzmann had good relationships with his students, and his kindness to students was acknowledged by all. In his later years Boltzmann never allowed anyone to fail. According to Lise Meitner, "His relationship with the students was accented by its humanity. He considered not only the knowledge in physics of candidates who were, for instance, examined at the end of the semester but he also tried to appreciate their general character traits. External forms meant nothing to him, and he didn't shrink from using words laden with sentiment. From time to time he invited home the few students who took part in his advanced seminar. At those times he played for us – he was a very good pianist – and told us about various personal experiences.

Fitz Hasenohrl, Boltzmann's outstanding student and immediate successor, described his kindness: "The successes of the scientist require talent and intellect, but the teacher must have his heart in the right place. Characteristic of the good teacher – at the elementary as well as the university level – are ability to understand those who are learning, interest in their development, good will, and sympathy. In a word, the good teacher is characterized by a kind heart. Those were the personal traits that made Boltzmann a brilliant teacher and that assure him of the everlasting gratitude of his many students. The way in which Boltzmann got on with his students has remained indelible in their memories. He never played up his superiority: everyone was at liberty to ask questions and even to criticize him. One could converse with him in an uninhibited way as if between equals, and often one noticed only subsequently how much one had learned from him once again. He did not measure others with the yardstick of his own greatness. He also judged more modest achievements with goodwill, so long as they gave evidence of serious and honest effort."

Music and the art had a special role in Boltzmann's life. He was a talented pianist. By no means did he prize beauty only outside the realm of science. He made great fun of the absurd pedantry with which Schopenhauer tried to classify the arts to read rules into them. Admiration of Boltzmann from art and beauty can be well understood from his express: "I once laughed when I read that a painter spent days and nights looking for a single color, but I don't laugh about it any more now. I cried when I saw the

color of the sea; how can a mere color make one cry? Or moonlight, or the luminescence of the sea in a pitch black night? … If there is one thing which is more worthy of our admiration than natural beauty, it is the art of men who have conquered this never-ending sea so fully in a struggle that has been going on since the time of the Phoenicians and even longer … Truly, the greatest wonder of nature is the skillful mind of man! If were asked, as was Solon, whom I take to be the happiest among mortals, I would name Columbus without hesitation. Not that there have been no other discoveries of equal merit, that the German, Gutenberg, for example. But happiness is partly conditioned by the sensual effect, and that must have been strongest in the case of Columbus!"

One of the most attractive qualities of Boltzmann was his incomparable sense of humor. It is not needed to bring some example of it, as it can be seen throughout his lectures and writings. He commented: "When I harmlessly adopted my usual tone on the first day in the Berlin laboratory, a single glance from Helmholtz made it clear that cheerfulness and humor did not befit the scholar. When I later described this glance to Herr Glan, then an assistant, now a professor, he replied haughtily: 'After all, you are in Berlin!'" Although, he accepted the offer of the Kirchhoff's chair in Berlin, he did not go. This might be due to an acid comment by Frau Helmholtz: "Herr Professor, I am afraid you will not feel at home in Berlin!"

Boltzmann's friends called him childlike attitude, naiveté, or unworldiness. Alois Hofler, his student and later a reputable philosopher, described him as "powerful man, but childlike to the point of childishness". Ostwald called Boltzmann a "stranger in this world". The reason for calling him by his friends naiveté was due to his resistance to uncritical acceptance of traditions and conventions, that is, the desire to approach problems in science as well as in life in an open way, according to his own best judgment. His achievements prove that also in everyday life he was conscious of his goal, but his actions were often unusual for others. For instance, after buying a cow for his country house he is said to have consulted his colleague, the professor of zoology, to find how to milk the cow.

Boltzmann's capacity for work was truly wonderful. He thought in different academic chairs as professors of mathematic, mathematical physics, theoretical physics, and experimental physics. There were many course he thought such as the principle of the mechanical theory of heat, elasticity, the mathematical theory of acoustics, mathematical theory of capillary, the theory of calculus, differential and integral calculus, number theory, special topics in advanced analysis, analytical geometry, the theory of functions, analytical mechanics, gas theory, theory of electricity and magnetism, optics and acoustics, thermodynamics, and in the last years of his life principles and special topics in natural philosophy was also added to this long list. Moreover, he announced that would teach elasticity and hydrodynamics in the winter semester of 1906-1907.

H. A. Lorentz, the famous theoretical physicists admired Boltzmann's relationship to theory on one hand and to experiment on the other: "Boltzmann did some beautiful and important works in the experimental area in the early years of his career and he often eloquently proclaimed his praise for experimental physics. Sometimes he almost seemed to envy experimental physics because of the reliability of its results and because of its smoothly advancing development. Yet in the depths of his heart he was

a theoretician; he loved to emphasize this in seriousness and in jest, and never stopped referring to the task of developing theory and of clarifying and consolidating its fundamentals as his task in life." In addition to his fame as a theoretician, he was admired by many scientists as a great experimentalist. For examples, Lorentz and Des Coudres referred to Boltzmann's experimental skill. Ernst Mach, who was an outstanding experimental physicist, called Boltzmann a "hard-to-beat" experimenter.

Boltzmann's writings were also lively as well as his lectures. According to Lorentz: "In many of these [writings] he speaks to us as a physicist seldom does, and reveal to us his entire way of thinking and feeling in words that also bring him closer to our hearts … Here he shares with us his doubts and his joys; here he captivates us with profound, serious intellect and light-hearted wit; here he carries us along through his consistent mechanical view of Nature, or through his enthusiastic idealism, which moves him to embellish his works with so many poets' work … There are contradictions in the pictures painted by him that he does not hesitate to display clearly or even glaringly; yet we feel that they are not irreconcilable, but that they spring from a certain root in the innermost part of his being, and that through them he allows us a deeper look into his mind."

Boltzmann's Critiques of Other Philosophies

Firstly, it is appropriate to mention some critiques Boltzmann made against other philosophies. Within these critiques, it is possible to see Boltzmann worry about danger of popular philosophies expressed by certainty for public. Two typical examples were mentioned here. Since it is often thought that Boltzmann's critique of traditional philosophies is due to his personal dislike, an example from traditional philosophy and another regarding a philosophy expressed by scientists in the field of philosophy of science are noted.

On a Thesis of Schopenhauer

In a lecture delivered to the Vienna Philosophical Society on 21 January 1905, Boltzmann criticized all of Schopenhauer's philosophies and showed he is a stupid, ignorant philosopher, scribbling nonsense and dispensing hollow verbiage that fundamentally and forever rots people's brains. These words were taken from own Schopenhauer, as he has used them against Hegel. However, as Boltzmann strongly criticized Schopenhauer's vocabulary, he simply named his lecture "On a thesis of Schopenhauer".

He expresses the aim of his essay as "I wish to speak not on a thesis of Schopenhauer's but about his whole system, though certainly not to furnish a complete critique but merely some sketchy thoughts on the subject." In fact, he tries to show that the problem of Schopenhauer's philosophy is not due to proposition of a weak theory, but the problem is merely metaphysical base of his thoughts which led him astray in all of his beliefs. Some examples of these blind mistakes due to lack of appropriate realistic view, as described by Boltzmann, are given below.

At the first, Boltzmann talks about contradiction of the Schopenhauer's definition of space and time with the modern theories of space and time (at his time). He continues by emphasizing on carelessness of Schopenhauer in using "a priori". Boltzmann criticize the claim of Schopenhauer that it is a priori that space has three dimensions, by noting that it is known that a space of more than three dimensions is conceivable and even a non-Euclidean. He makes a similar critique of Schopenhauer's inference from the principle of sufficient reason that the law of conversation of matter is clear a priori. He expresses: "Landolt has conducted experiments on precisely this law, and his findings seemed at first to contradict it. Today it is indeed more likely that they will not be able to impair the law of conversation of matter, but what is important here is not the results of his experiments but merely whether experiments are as such able to refute laws, or whether logic can prescribe the paths that the pointer on Landolt's scales must take. For a second time doubts about this law have arisen in connection with the behavior of radium. I am convinced that these experiments too will confirm the law, but that proves the law to be other than a priori: were it not to hold, we could retort nothing from a logical point of view." Nowadays, we understand well Boltzmann view, since the law of conversation of matter was replaced by a more general theory namely the law of conversation of matter and energy. Moreover, in the light of Boltzmann's philosophy of theories, it is possible to understand that the law of conversation of matter is not a priori (as inferred based on metaphysical assumptions by Schopenhauer), but it is just a theory proposed by human brain which would be replaced by another one (a better theory), as it was already done for this case.

Then, Boltzmann elaborates subtle protests of the concept of will proposed by Schopenhauer. Regarding Schopenhauer's description of will for typically a stone, Boltzmann says: "This is quite an ingenious remark, but if Schopenhauer is now firmly convinced that by using the same work will for forces of inorganic nature and for certain psychological processes what we experience in ourselves he has made colossal strides in our knowledge of nature, he really yields to a rather naïve illusion." He comes to Schopenhauer's proposition of the concept of freedom, which suggests the will as subject, as thing in itself, is necessarily and unconditionally free, since causality has no purchase on thing in themselves and it is completely free under different external circumstances to act quite differently, but the actions of the will, its manifestations, its objective realization under given circumstances are completely determined by these latter and thus completely unfree and from the freedom of the will as thing in itself we can explain the obscure the obscure feeling that occur actions too are free. In this context, Boltzmann just provides a subtle contradiction which arises from the Schopenhauer's proposition: "if the will aims at its destruction it no longer depends on anything and a moment of freedom supervenes."

Boltzmann shows, in detail, waste endeavor of Schopenhauer to apply his hypothesis to different arts. He explains that even classification of different arts by Schopenhauer does not promptly cover any possible art. Moreover, the distinction made by Schopenhauer between music and other arts, as music is the direct representation of the will in so far as it is not object whereas all other arts also represent will but only indirectly as an individual objective form of it, suffers from lack of realistic view leading to funny consequences and severe contradictions. If we try to imagine that music is direct representation of the will, thus "if the ground bass is supposed to resemble the mineral kingdom, the lower intermediate voices the kingdom of planets,

the higher ones the animal kingdom, and the descant the realm of man.", as Boltzmann says. According to Schopenhauer, music is a mirror of the whole world, the world being one manifestation of the cosmic will and music another achieved by different means and independent of the first. Thus, music could continue to exist if the world did not, which means in the case that there are no violins, sound-transmitting air, excited ears, perceiving minds.

Boltzmann criticized superficial antipathy of Schopenhauer towards the male beard. In spite of empty reasons for such opinion, Boltzmann notes that such opinion is not merit for an outstanding philosopher. Boltzmann concludes: "We see how a philosopher who regards aesthetics only from a theoretical angle can go astray. The result, using Schopenhauer's mode of expression, is this: 'Stupidity, simple-mindedness, foolishness, mental daubing, folly, eccentric nonsense, cranky obtuseness, imbecility that cries to high heaven'. I hope this load of dynamite is enough."

Finally, he comes to the main problem, which addressed as 'thesis' in his essay title, namely ethics. Indeed, the dangerous result of Schopenhauer's philosophy is the deduction he made to describe ethics. In other words, his theory of the will is just a theory among many ones proposed in philosophy. But what makes his theory dangerous and classifies it as dark philosophy is that he deduces from his whole theory of the will that life is a misfortune. Above all, he suggests the only way to achieve happiness is the will's denying itself and in one's preparing the transition to nothingness. He also emphasizes that this is the only correct ethics. Boltzmann expresses that this is not an original idea merit of a Western philosopher in modern era, but it is simply possible to derive it from an ancient Eastern belief. In addition, he simply explains based on some theoretical speculations that hoping for such nothingness is in vein, and talking about the existence of nothingness is a kind of waste thinking. Even, it is not needed to use modern physics to understand this fact.

After such arguments, Boltzmann comes to the main aim of his essay to say "it is utterly wrong to regard it as the task of ethics to deduce from metaphysical arguments whether life as a whole is a happy or an unhappy circumstance." Then, he distinguishes the domain ethics as: "Ethics must therefore ask when may the individual insist on his will and when must he subordinate it to that of others, in other that the existence of family, tribe, or humanity as a whole and thereby of each individual is best promoted."

On Energism

Based on Mach's philosophy, a kind of ideology was born at the end of nineteenth century, mainly in Germany, referring all natural phenomena to the reality of energy. From the beginning, Boltzmann strongly criticized this philosophical view developed by some outstanding scientists, mainly Wilhelm Ostwald. Here, some of his critiques against energism are noted. Interestingly, it can be understood from this criticizing that not only deriving philosophical theories merely from metaphysical speculations, but also Boltzmann criticized scientific-based theories when they suffer from appropriate realistic view. This type of philosophical theories are usually based on misunderstanding of human-created theories by assuming them as natural real facts,

and emphasizing on a single application not appropriate generalization to the whole system In addition, as he states the main problem of such theories is that they try to formulate philosophical problems with mathematical certainty. This opinion of Boltzmann can be well understood from his typical critique of energism, as given below.

Boltzmann notes that it is not appropriate to consider both physical energy and mental energy the same, though the same word is employed for them. “In natural science energy is a magnitude that can be measured in suitable units always maintains itself in quantity so that if it vanishes in one place an equal amount always appears somewhere else. Only if it had been proved that when mental energy is developed an equivalent amount of physical energy always actually disappears, that is if mental energy can be measured in such units that the amount developed was always exactly equal to the physical energy lost, should we be entitled to speak of mental energetics. The proof of this proposition has however by no means been achieved, indeed everything points to it being impossible, and that because it is completely false. The perfect parallelism between mental phenomena and physical brain processes makes it probable that all energy is constantly maintained in its physical form within the brain mass, whole mental processes are merely parallel epiphenomena without energy, indeed perhaps merely a second mental picture of the same phenomena viewed from another angle, which can thus certainly not contain any new sort of energy in the physical sense.”

Boltzmann indeed provides a beautiful reason to spurn the superficial relationship between physical energy and mental energy. We now know, after many discoveries of modern physics brining into mind completely new definition of energy and many progresses in understanding the brain processes resulting in mental phenomena, that such direct relationship between physical energy and mental energy is impossible. Then, Boltzmann shows by a simple question that, even conquering the problem to have such mutual action between body and mind, the main problem is still the difference of energy of will and known energy in natural science. “Imagine a very energetic man, he begins by waking up and down in his room and makes decisions, then he conveys them to the members of his family, his friends, and his subordinates in clear and decisive words, managing to ensure that they all carry out what he was aiming at. All these processes no doubts require a certain amount of physical energy, since they are accompanied by physical processes of the brain mass and the limbs. Let us now compare this with the case of neurasthenic who madly runs about his room, storming and cursing, scolding and shouting at those round him, and all this merely because he is in doubt whether the weather will remain good and he cannot decide whether he is to go for a walk or stay at home. Are not all the indications that his activity consumes as much if not more physical energy that that of a strong-willed man, and yet it is the latter who produces the highest mental energy and the former none.

With a beautiful sense of responsibility, Boltzmann emphasizes that this is not true to introduce such theories to public from the scientific throne. “If, however, physical energy and what I called mental energy are two totally different things called by the same name because of a rather superficial similarity, I think it is mistaken, because productive of false ideas and leading to error, when people speak without distinction of an energetic theory of mechanics, chemistry, mental phenomena, happiness, and so on.”

In spite of lack of appropriate suppositions for deriving energism, Boltzmann states that it was a misunderstanding of Ostwald from Mach's philosophy. "However, as regards Ostwald's energetics, I think it rests merely on a misunderstanding of Mach's ideas. Mach pointed out that we are given only the law-like course of our impressions and ideas, whereas all physical magnitudes, atoms, molecules, forces, energies and so on are mere concepts for the economical representation and illustration of these law-like relations of our impressions and ideas. These last are thus the only thing that exists in the first instance, physical concepts being merely mental additions of our own. Ostwald understood only one half of this proposition, namely that atoms did not exist; at once he asked: what then does exist? To this his answer that it was energy that existed. In my view this answer is quite opposed to Mach's outlook, for which energy as much as matter must be regarded as a symbolic expression of certain relations between perceptions and of certain equations amongst the given phenomena."

The main objection Boltzmann made to energetics was Ostwald's expression of the magnitude of happiness by means of the algebric formula $E^2 - W^2 = (E + W)(E - W)$, where E denotes the energy spent intentionally and successfully, and W that spent with dislike. First, Boltzmann emphasizes on the lack of mathematical appropriation for this case: "On this I must comment that a genuine mathematician puts definite power into a formula only if it has been found by exact measurements that just this and no other power is required to obtain agreement with experience. Has Ostwald proved that $E^4 - W^4$, $E^n - W^n$ or many similar formulae agree less well with the experience?" Then, he notes that this is just definition of happiness is just the conviction of an enterprising Western European, not a universal definition of happiness. For instance, Buddhists, who believe in the mortification of the will, will write it as $(E - W)/(E + W)$. He states that this formulae uses the corresponding operations just symbolically with the lack of any applicability of law of calculation; thus is different from that of known mathematical formulae. In addition, he adds, "this formula does not provide any practical hits for life and contributing to this happiness, and just suggests 'be energetic and see to it that everything happens according to your will'; and this is what everybody ones even without a mathematical formulae."

Boltzmann continues his critique by noting various obvious examples contradicting the Ostwald's definition of happiness. Such statements can be found in his original essay entitled "Reply to a lecture on happiness by Prof. Ostwald", and are not reported here. In general, Boltzmann tries to emphasize that such complicated natural phenomena such as human feelings and sensations resulting in happiness cannot be simply formulated by scientific theories.

In conclusion, he remarks, "Why does such a seemingly harmless essay like Ostwald's appear to me to be so dangerous to science? Because it signals a reversion to satisfaction with the purely formal, reversion to the method of so-called philosophers which is so pernicious to progress; to construct theoretical structures out of mere words and phrases and to place value only in their nice formal connections, what was known as the purely logical or even as the a priori approach, but not to take care whether these connections corresponds exactly to reality and are sufficiently rooted in facts; a reversion to the method of allowing oneself to be governed by preconceived opinions, of bending everything to the same principle of classification,

of wanting to see true mathematics in favor of algebric formulas, true logic in factor of apparently school-correct syllogisms, true philosophy in favor of nonsense decked out to look philosophical, the forest in favor of the trees …"

Boltzmann's Philosophical works

Here, some philosophical concepts originally proposed by Boltzmann are addressed. Similar to his other works, an objection to dogmatism can be seen. Indeed, he tries to lead both science and philosophy to a path ending to human evolution. In other words, admiring a kind of philosophy which can really assist human in the way of philanthropic progress. It is the reason that he called his philosophy realism.

Boltzmann's Natural Philosophy

Boltzmann's philosophy was related to the main problem of epistemology, the relationship of existence and consciousness. In this direction, he generalized his experience as a physicist and a protagonist of atomistic, and dealt with the essence of physical theories and the mechanism of their evolution. Boltzmann insisted on the necessity of accepting the reality of the external world, unless one wanted to embrace solipsism. Thus, he called his philosophy realism, and later materialism.

In spite of interesting philosophical works he proposed, the interesting feature of Boltzmann's natural philosophy was his philosophical view to analyze problems of epistemology. Indeed, his way of study was brilliant among other types of philosophy.

He called his philosophy realism. As he himself states: "The idealist compares the assertion that matter exists just like our sensations to the view of the child that a beaten stone suffers pain. The realist compares the assertion that one can never conceive how mental phenomena can be represented through matter or even through a play of atoms with the opinion of an uneducated person who maintains that the Sun cannot be 20 million miles (German miles) from the Earth, as he cannot imagine it. As ideology (idealism) is only a view for one individual, but not for mankind, to me the terminology of realism appears more useful that that of idealism. If we want to include the animals, nay Universe."

Boltzmann believes that the power of theoretical thinking can ultimately be explained on an evolutionist basis. Only mental processes that proved their worth during the long march of living matter from its beginning to the emergence of man could maintain themselves. More exactly, only the capacity for processes that made possible the correct understanding of nature could be transmitted to progeny. He describes, "Finally, the close connection of the mental with physical is given to us by experience. Through experience it is highly probable that a material process in the brain corresponds to any mental process, i.e. the latter is unambiguously coordinated to the former, and that the mental processes always are genuine material processes … Then it must be possible to predict all mental processes from the picture serving that representation of brain processes. The brain is considered by us as the instrument, the organ for the production of world pictures, which because of their great utility for the preservation of the species according to Darwin's theory developed to particular

perfection in man, as in the giraffe the neck, and in the stork the beak developed to unusual length … As soon as we follow this view, we have to assume that the pictures and laws serve to represent processes in non-living nature are sufficient to represent unambiguously all mental processes as well. We say briefly: the mental processes are identical with certain material processes in the brain (realism)."

Obviously, Boltzmann was an evolutionist not only because Darwin had put forward a powerful theory for a most important area of science that was not Boltzmann's. Rather, Boltzmann considered Darwins's method as the key for the understanding of truth or falsehood of scientific theories. It must be critically pointed out that Boltzmann did not distinguish between biological and cultural evolution, i.e. between what is psychologically fixed, and what is handed down to descendants in human society example and precept.

For Boltzmann, his science and his philosophy were a unity, as is also implied in his grand, all-embracing use of the term "mechanics". What can be achieved from Boltzmann's philosophy is his method in epistemology. Indeed, the memento of Boltzmann for philosophy was his wish for collaboration of philosophy and science. In his opinion, These two sciences, by assisting to each other and combination together, can to solve many epistemological problems. However, what is needed to reach this goal is necessity of a realistic view and anti-dogmatic thoughts.

Philosophy of Theories (Theoretical Pluralism)

Boltzmann's philosophy of theories is the main part of his philosophical works. During all of his active life devoted to both scientific and philosophical studies, Boltzmann had a particular emphasis on the importance of theories and has mentioned it throughout his writings. His philosophy of theories, which is known as theoretical pluralism, is brilliant among various philosophies.

Boltzmann himself with modesty noted that the idea suggesting 'there is no ultimate theory' has also been previously mentioned by different philosophers and scientists, such as Kant and Maxwell. What is obvious is that none of his predecessor thinkers understood the importance and significance of the fact described by Boltzmann, i.e. 'theory just as a representation'. Referring to previous thinkers is merely due to Boltzmann's modesty, or perhaps to achieve a credit for his philosophy in the presence of his obstinate opponents. In the very manner that he used Mach's opinion "Mach himself has ingeniously discussed the fact that no theory is absolutely false either, but each must gradually be perfected, …". However, Boltzmann was the first one who formulates and makes clarification on the concept of so-called theoretical pluralism.

Theoretical pluralism says that a scientific theory is nothing more than a representation of nature. Indeed, it is not possible to know nature via discovery of its law describing why the natural phenomena are in the way they are, and why they show themselves to us the way we observe. In fact, such ultimate science (knowledge) is not attainable to human. As Boltzmann says two questions falls out of human understanding: why we are here, and why we are in the present. There is no hope for science, and also philosophy, and generally human sciences to answer these questions.

In the light of theoretical pluralism, it is possible to clarify the terminology of this context. The laws of nature are the original laws which the natural phenomena obey from them, and cannot be discovered by human. But, the laws of physics are those invented by human to explain the natural phenomena. Thus, a theory is not discoverable, but should be invented by human mind.

In this direction, a scientific theory will not be complete or definitively true. In other words, even an apparently successful theory may be replaced by a better one. On the other hand, different theories, with contradiction in respect to each other, can successfully explain a single natural phenomenon. A theory is initially a free creation of the theorist who proposed it from a purely personal perspective, metaphysical presuppositions, theoretical options, preferences for a certain type of mathematical language, and the dismissal of some observial data. In Boltzmann's opinion, as all theories are, to some extent, free creation of the theorists, it is not possible to find a theory formulated from the mere observation of natural phenomena.

As Boltzmann states: "Hertz makes physicists properly aware of something philosophers had no doubt long since stated, namely that no theory can be objective, actually coinciding with nature, but rather that each theory is only a mental picture of phenomena, related to them as sign is to designatum. From this it follows that it cannot be our task to find an absolutely correct theory but rather a picture that is, as simple as possible and that represents phenomena as accurately as possible. One might even conceive of two quite different theories both equally simple and equally congruent with phenomena, which therefore in spite of their difference are equally correct. The assertion that a given theory is the only correct one can only express our subjective conviction that there could not be another equally simple and fitting image."

Since there is no ultimate theory, a completely true one, it is necessary to find good theories. The aim of a theory is to explain a natural phenomenon, thus, a good theory is the one which is simple. Consequently, our task is to seek for better theories in accordance with their applicability, not to find truer ones.

In Boltzmann's words: "It follows that it cannot be our task to find an absolutely correct theory, but rather a picture that is as simple as possible while representing the phenomenon as well as possible. It is even possible to imagine two different theories that are equally simple and equally good in explaining the phenomena. Both, although totally different, would be equally correct. The assertion that a theory is the only correct one can only be an expression of our subjective conviction that there can be no other equally simple and equally fitting picture."

Boltzmann's Anti-Dogmatism

One of the most interesting features of Boltzmann's philosophical view was his opinion against dogmatism. In other words, he emphasizes on dogmatism as a dangerous poison for human sciences including both natural science and philosophy, and particularly epistemology. "Simple consideration as well as experience show that it is hopelessly difficult to find the right pictures of the world by mere guessing into

the blue. Rather, the pictures always form slowly from individual lucky ideas by fitting. Rightly epistemology turns against the activities of the many lighthearted producers of hypothesis who hope to find a hypothesis explaining the whole of nature with little effort, as well as against the dogmatic and metaphysical derivation of atomistics."

Objection of atomism was an obvious dogmatism, which Boltzmann had to oppose it. He states: "The reproach that the observed immutability of atom, lasting only limited time, has been generalized without reason would certainly be justified if one tried to prove, as used to be done, the immutability of atoms a priori. We include it [immutability] in our picture merely to represent as many phenomena as possible … We are ready to drop immutability in cases where another assumption would represent the phenomena better."

In fact, Boltzmann was sacrifice of the scientific dogmatism of his time. According to Flamm, "Boltzmann was a martyr to his ideas". Unfortunately, the objections made to him were not scientific discussions, but mere dogmatisms. This is obvious from the objections made to him regarding atomism, since they just were positivism beliefs. In other words, Mach defended his philosophical opinion. According to Max Planck, who was initially opponent to Boltzmann and later converted and used his approach, "Against the authority of men like Ostwald, Helm, and Mach there was not much that could be done."

Unfortunately, dogmatism still exists in both science and philosophy. Boltzmann tried to destroy dogmatic views in both scientific and philosophical thoughts throughout his life. Appearance of dogmatism in philosophical thoughts is common, since it existed throughout the history of philosophy. Boltzmann tried to desolate it by introducing a realistic view in epistemology via his natural philosophy and particularly his theoretical pluralism.

Scientific dogmatism was also very important in his time. Not only the dogmatic objection of atomism, but also dogmatic view about thermodynamics and its second law were common that time. Before Boltzmann's view, all physical laws had to be strictly deterministic and universally valid. The most of physicists believed in this view for thermodynamics. They believed that the second law of thermodynamics was a basic axiom handed down from God, which one had to accept as the starting point of any thermodynamic consideration. Whereas, Boltzmann used a statistical interpretation of the second law, about 50 year before the statistical interpretation of quantum mechanics.

Similar dogmatisms still exist in science, and particularly in cosmology. Since the significant progress of astrophysics flatten the path for using cosmological theories in explaining epistemological problems, indeed such scientific dogmatism are not tied with classical philosophical dogmatism. It is now believed (by some cosmologists) to avoid the appearance of such scientific-philosophical dogmatism in cosmology and epistemology, which is the main obstacle in the progress of science and philosophy and in general human knowledge, is just to use Boltzmann's view.

Boltzmann's Memento for Future Philosophy

When talking about Boltzmann's philosophy, it is usually referred to his dislike of philosophy. It is thought that the whole of his activities in the field of philosophy is to deny and to condemn it, particularly due to his condemnation of famous philosophers. Indeed, it is the main reason avoiding appropriate consideration of his philosophy in the philosophical communities. Whereas, none of the scientists, who entered into philosophy, has valued philosophy as Boltzmann did. Weak understanding of Boltzmann's philosophy in the philosophical community is due to misleading of his words reported in historical controversies.

For instance, his dislike is obviously related to metaphysics, not philosophy. He believes while philosophy is based on metaphysical arguments, no applicable result will be achieved. He expresses the need for a realistic view in philosophizing epistemological problems by comparing the case with waste history of natural science: "Likewise, the scientist asks not what are the currently most important question, but 'which are at present solvable?' or sometimes merely 'in which can we make some small but genuine advance?' As long as the alchemists merely sought the philosopher's stone and aimed at finding the art of making gold, all their endeavors were fruitless; it was only when people restricted themselves to seemingly less valuable questions that they created chemistry. Thus natural science appears completely to lose from sight the large and general questions; but all the more splendid is the success when, groping in the thicket of special questions, we suddenly find a small opening that allows a hitherto undreamt of outlook on the whole."

"[Questions about the essence of the law of causality, of matter, of force, etc] do not, it used to be said, concern the scientist; they should be left entirely to philosophy. Today this has changed considerably; natural scientists show a great prediction for taking up philosophical questions, and probably rightly so. After all, it is one of the fist rules in natural science never to put blind trust in the instruments with which one works, but to test it in every way. Are we then to put blind trust in inborn or historically developed concepts and opinions, all the more so in view of all the examples in which they have led astray? But when we examine the simplest elements, where is the borderline between natural science and philosophy at which we should stop? I hope that none of the philosophers possibly present will take it amiss or feel reproached if I say frankly that the assignment of these questions to philosophy has perhaps also led to disappointment. Philosophy has contributed remarkably little to the eludation of these questions. Alone and from its one-sided point of view it could do it just as little as natural science can. If real advances are possible, they are only to be expected from collaboration between the two sciences."

In other words, his sharp critism of the majority of previous philosophers does not prevent him from acknowledging the proper domain and positive role of a genuine, progressive philosophy. He gladly references to the irresistible derive of human beings to philosophize and wishes for collaboration between philosophy and natural science. In his words: "It is because of my firm hope that a congenial collaboration between philosophy and natural science will bring new food to each, indeed that we can achieve a truly consistent exchange of views only by following this path, that I have not avoided philosophical questions here. When Schiller said to the philosophers and natural scientists of his day: 'Let there be enmity between you, alliance comes too

early yet,' then I am not in disagreement with him I just believe that now the time for alliance has arrived."

What provides credit for philosophy in Boltzmann system is due to his method of natural science. The controversy appearing between philosophy and natural science is usually due to two main critiques scientists make to philosopher: (i) standing on the base of theories, and (ii) lack of mathematical considerations and just using descriptive arguments. Both of these methods can be found in Boltzmann's system. He always emphasizes on the importance of theories and on the need for descriptive science. Here, Boltzmann's opinions regarding such requirements for the development of human science and the reason why philosophy went astray by misusing of them are given.

He defines theory as: "I am of the opinion that the task of theory consists in constructing a picture of the external world that exists purely internally and must be our guiding star in all thought and experiment; that is in completing, as it were, the thinking process and carrying out globally what on a small scale occurs within us whenever we form an idea." Then, he describes what make a theory applicable or valuable: "The immediate elaboration and constant perfection of this picture is then the chief task of theory. Imagination is always its cradle, and observant understanding its tutor. How childlike were the first theories of the universe, from Pythagoras and Plato until Hegel and Schelling. The imagination at that time was over-productive, the text by experiment was lacking. No wonder that these theories became the laughing stock of empiricists and practical men, and yet they already contained the seeds of all the great theories of later times: those of Copernicus, atomism, the mechanical theory of weightless media, Darwinism and so on."

Indeed, he tries to show that the mistake of philosophers was not due to devotion to theoretical considerations, which is indeed the task of philosophy, but the big mistake they made was due to proposition of their theories based on purely metaphysical arguments.

Boltzmann believes that there is no necessity for a good theory to have mathematical formulae, and descriptive sciences can also provide such a good theory in the absence of any mathematical considerations. He beautifully defines theory: "I should not be genuine theoretician if I were not first to ask: what is theory? The layman observes in the first place that theory is difficult to understand and surrounded with a tangle of formulae that to the uninitiated speak no language at all. However they are not its essence, the true theoretician uses them as sparingly as he can; what can be said in words he expresses in words, while it is precisely in books by practical men that formulae figure all too often as mere ornament."

Although, he was extraordinarily talent in mathematics, and surely he had an excellent skill in mathematics among other physicists of that time (recall that he was appointed as professor of mathematics in University of Vienna), he never took up mathematical problems for their own sake but always with an eye toward application. In his enthusiastic words: "I called theory a purely intellectual internal picture, and we have seen how capable it is of high perfection. How then could it now happen that on continuing immersion into theory one comes to think of the picture as of the really existing thing? … Thus it may happen to the mathematician that he, always occupied

with his equations and dazed by their internal perfection, takes their mutual relationship for what truly exists, and that he turns always from the real world. Then the lament of the poet applied to him as well: that his works are written his heart blood and that highest wisdom borders on highest folly."

According to this fact, the style of Boltzmann's writing was different of other physicists (as stated above in the words of Lorentz). Even the ingenious Maxwell, who in 1859 had described the velocity distribution of gas molecules in thermal equilibrium, wrote the following in a letter to his colleague Peter Tait in 1873: "By the study of Boltzmann I have been unable to understand him. He could not understand me on account of my shortness, and his length was and is an equal stumbling block to me." If Maxwell found Boltzmann' s papers difficult, it is hardly surprising that many other physicists found them difficult as well! This is probably an important reason why Boltzmann does not – even today – receive as much credit, as he deserves, particularly since most physicists have never read his original papers.

In conclusion, any attempt in epistemology without taking into account Boltzmann's philosophy is waste. Indeed, Boltzmann's theoretical pluralism is the basic foundation for proposition of any theory in epistemology. In other words, it is needed basically to know, in the light of Boltzmann's theoretical pluralism, that we just make a picture of the world, existence, and universe by proposing a theory. Otherwise, with aiming to find ultimate theory or discovering the law of nature, it just leads to dogmatism. Thus, it is necessary to learn the meaning of a theory (from Boltzmann's philosophy of theories), as basic alphabets of epistemology, since theory is the powerful (and also only) tool in epistemology.

Boltzmann's Materialism

Unfortunately, due to terminology problems appeared in the modern literature, it is difficult to express a context without definition of the key terms. For instance, the terms physicalism, materialism, and naturalism have been used in the literature with the same meaning, and where they have used for specified purposes there is no constant distinction between their meanings. Thus, it is necessary to note what is the purpose of Boltzmann from materialism, when referring to his philosophy as realism-materialism.

The formal definition of materialism is "the doctoring that noting exists except mater and its movements and modifications". When talking about materialism, it is usually recalled an agnosticism for denying the existence of God. Let first note the difference of Boltzmann's philosophy in comparison with the common materialism in accordance with the problem of the existence of God. As stated, the common materialism believes that nothing can be known concerning the existence of God, which caused many critiques from those who believe in God and particularly from religious standpoints. However, Boltzmann's philosophy is different as he stated:

"It is certainly true that only a madman will deny God's existence, but it is equally the case that all our ideas of God are mere inadequate anthropomorphisms, so that what we thus imagine as God does not exist in the way we imagine it. If therefore one

person says that he is convinced that God exists and another that he does not believe in God, in so saying both may well think the same thoughts without even suspecting it. We must not ask whether God exists unless we can imagine something definite in saying so; rather we must ask by what ideas we can come closer to the highest concept which encompasses everything."

Boltzmann used the term of materialism to deny the existence of a kind of human science namely metaphysics, and indeed employed the term materialism against philosophical idealism. Usually, opponent authors note personal dislike of Boltzmann from philosophy to criticize his philosophy. However, this is just a misleading view of his philosophy due to a superficial understanding of his sentences. When he expresses his dislike (and maybe hate) from philosophy, he indeed refers to a kind of philosophy which is based on metaphysics. Although, he calls the previous philosophers as great thinkers, he emphasizes how such great minds went astray when trying to use merely metaphysical speculations to answer empty questions regarding epistemology.

He states that the attempts of the metaphysicians to extend questions beyond their natural domain lead to the answers consisting only empty words without bringing any new knowledge. To criticize metaphysical-based philosophy, he notes: "Even [Francis] Bacon of Verulam, who stood at the cradle of inductive science, calls philosophy a hallowed virgin. He adds somewhat maliciously that she will remain eternally barren precisely because of this lofty quality. True, many investigations in metaphysics remained barren but we still want to test whether every speculation must really be unfruitful."

In conclusion, what Boltzmann refers to as materialism is different of that known commonly. In fact, Boltzmman's materialism claims the existence of external word and believes in science. This materialism does not claim that the truth of the existence of just material, but believes what we can know lies in the realm of science (physics). This does not claim that we can ultimately know what is really the universe is, but we can relatively understand it by proposing appropriate theories to make a picture of the nature for us.

Influence of Boltzmann on Modern Physics (Philosophical Importance)

Since philosophy of science was developed in the light of new discoveries of science in the field of modern physics, it is necessary to note the influence of Boltzmann on the birth and progress of modern physics in such biographical essay. Although, Boltzmann was a classical physicist, he had great influence on the formation of various parts of modern physics. However, some topics which are of interest in philosophy and for philosophers are noted here. Boltzmann's opinions regarding statistical description of the universe have philosophical importance but were not reported here, since a detailed explanation has been elaborated by Bradley Dowden in an article entitled "Time" in this series (Interne t Encyclopedia of Philosophy).

Atomism

Atomism was one of the important subjects of controversy among both philosophers and scientists. The importance of atomism is now obvious due to its essential role in modern physics. Boltzmann was one of the scientists who strongly insisted on atomism. Indeed, the main objection against Boltzmann's theory was the refutation of atomism at the end of nineteenth century. In this context, Ernst Mach, reputable physicist-philosopher, was among opponents, and other important scientists of that time such as physical chemist Wilhelm Ostwald. For instance, both of the mentioned persons were later converted, but not until the death of Boltzmann. However, Boltzmann defended atomism until his death in various polemic discussions.

He notes: "We shall not [in connection with the question of the atomic constitution of matter] appeal to the law of thought that there could be no limit to the divisibility of matter. This law is no better than the assertion of some naïve person that antipodes cannot exist because all vertical directions seem parallel, wherever one walks on Earth … For calculation shows that electrons are much smaller still than the atoms of ponderable matter. Today, everyone is talking about the hypothesis that atoms are built of numerous elements [constituents], and about various interesting views about the nature of atomic structure. We must not be misled by the word atoms, it has been taken from old times. No physicist ascribes indivisibility to atoms today."

Nowadays, the importance of Boltzmann's atomism for twentieth-century science is obvious, and indeed, Boltzmann's atomistic statistics paved the way for parts of modern physics and particularly quantum mechanics, as will be described below.

Statistical mechanics

Indeed, it is not necessary to note the essential role of Boltzmann on the formation of statistical mechanics, since he is well known as the main founder of statistical mechanics. It is worth noting that Josiah Willard Gibbs (1839 – 1903), great thermodynamicist is known as co-founder of statistical mechanics. Although different methods have been proposed to statistical mechanics, Boltzmann's statistical approach is still an interesting one and applicable for various purposes.

Thermodynamics and second law

Thermodynamics and its second law is an interesting part of philosophy of science, and have been widely described in the philosophical literature. At the first look, it seems to be strange that philosophers have interest in the science of temperature changes (thermo: heath, and dynamics" changes), which was invented by engineers for study of heat engines. In fact, this universality of thermodynamics and its second law is due to the statistical view introduced by Boltzmann. By definition of entropy from a purely statistical standpoint, Boltzmann made a generalization to use the concept of entropy for all phenomena, not only those involving temperature changes.

Indeed, Boltzmann conquered the contradiction between thermodynamics and mechanics by relating increases in entropy to transition from the improbable to probable states. According to Max Planck (1858 – 1947), who was at the first follower of Mach and opponent of Boltzmann and later admirer of Boltzmann as converted to atomism and Boltzmann statistics, "among all physicist of that time,

Ludwig Boltzmann was the one who grasped the meaning of entropy most profoundly."

However, Boltzmann's entropy is one of the most beautiful concepts in physics, which have been used by philosopher. Even, Boltzmann himself used the concept of negentropy (negative entropy) to explain the nature of living beings: "The general struggle for existence of living beings is therefore not a fight for the elements – the elements of all organisms are available in abundance in air, and soil – , nor for energy, which is plentiful in the form of heat, unfortunately untransformably, in every body. Rather, it is a struggle for entropy [more accurately: negative entropy] that becomes available through the flow of energy from the hot Sun to the cold Earth. To make the fullest use of this energy, the plants spread out the immeasurable areas of their leaves and harness the Sun's energy by a process as yet unexplored, before it sinks down to the temperature level of our Earth, to drive chemical syntheses of which one has no inkling as yet in our laboratories. The products of this chemical kitchen are the subject of the struggle in the animal world."

Quantum theory

Quantum mechanics was one of the most important parts of modern physics which led to philosophical consequences. In fact, by quantum mechanics a new aspect of science was introduced to philosophy. Quantum theory was introduced at the present form by Max Planck in 1900 and he is known as founder of it. However, Ludwig Boltzmann and Max Planck are referred to as father and mother of the quantum. According to Arnold Sommerfeld, "the quantum theory would have been the proper field of activity for Boltzmann's atomistically structured intellect."

In addition to the fact that Planck proposed the quantum theory using Boltzmann statistical view, Boltzmann used the notion of energy quantization, without using this term, in his papers as early as 1872, 28 years before Planck's publications. He at first divided the energy of a system into extremely small, discrete packages. Boltzmann conceived of this quantization as a kind of mathematical trick to permit the use of combinational equations in computing probabilities. Energy quanta did not appear any more in the final equations, but there can be no doubt that Boltzmann through his approach helped to prepare the way for quantum theory.

Thermodynamics of irreversible processes

Non-equilibrium thermodynamics or thermodynamics of irreversible processes is known as a capable field of modern physics and is of great interest in philosophy. It was born due to new thoughts of nineteenth century scientists to the importance of non-equilibrium states, irreversibility and irreversible process. In this context, Boltzmann had the most importance influence through mating the kinetic theory of gases to thermodynamics. He proposed an equation, which is internationally known as Boltzmann's equation. He also established statistical methods for the investigation of physical systems, and is considered as the main founder of statistical mechanics which is an important part of modern physics. Boltzmann discovered such models based on behavior of atoms, while, atoms had not been proofed in his time, and thus he is known as "the man who trusted atom". Boltzmann's equation for the evolution

of the distribution of the position and velocity of particles in a fluid not only handles non-equilibrium situations but is quite non-linear.

Following Boltzmann's statistical view, Lars Onsager have used statistical mechanics to investigate irreversible processes in the 1920s, and published his results in 1931. Onsager was awarded the Nobel Prize in Chemistry in 1968 for initiating non-equilibrium thermodynamics. Indeed, he was awarded for the discovery of the reciprocal relations bearing his name, which are fundamental for the thermodynamics of irreversible processes. After formal introduction of irreversible thermodynamics, Ilya Prigogine at Brussels School (the academic institute which made significant contributions to thermodynamics of irreversible processes) took an important step in the development of non-equilibrium thermodynamics. He also began to dispute the orthodox ideas of statistical mechanics, according to which the fundamental laws of physics are reversible, and the irreversible phenomena of everyday life and physical chemistry arise statistically. He was awarded the Nobel Prize in Chemistry in 1977 for his contributions to non-equilibrium thermodynamics, particularly the theory of dissipative structures.

In this direction, Prigogine in 1945 elaborated the theorem of minimum entropy production applicable for non-equilibrium stationary systems. Prigogine showed that the famous reciprocity relations of Onsager, which are very good approximations for the study of transport phenomena, are not valid for the systems far from equilibrium. The importance of this achievement was due to the fact that the most of natural systems are far from equilibrium. In other words, he extended thermodynamics to open systems, which is of great interest for study of living organisms. Prigogine attempted to extend the Boltzmann's method of statistical mechanics to condensed systems, the first tentative step in non-equilibrium statistical mechanics was taken, and he achieved a formulation of non-equilibrium statistical mechanics from a purely dynamical point of view, without any probabilistic assumption, which leads to a "dynamics of correlations", as the relation between interaction and correlation constitutes the essential component of the description.

In addition to valuable contributions of the theory of dissipative structures proposed by Prigogine to non-equilibrium thermodynamics, his theory has made significant contributions to other fields of sciences and can be considered as a universal law. Indeed, the main theme of the scientific work of Prigogine has been a better understanding of the role of time in the physical sciences and in biology. The works of Prigogine has significant philosophical and cultural importance and have been employed in social sciences.

Through many contributions made to the thermodynamics of irreversible processes, mainly due to the works Prigogine, it has been achieved a considerable attention for philosophical tasks. However, both physical and philosophical importance of irreversible processes was first by Boltzmann. According to Sommerfeld, "no one, not even Maxwell or Gibbs, pondered the one-sidedness of natural processes and their probabilistic-theoretical foundation as deeply as Boltzmann. Ludwig Flamm said: "By developing the counting methods of physical statistics and by deriving the Second Law of Thermodynamics with their aid in a very general way, Boltzmann gave to physics new foundations of entirely unexpected dimension."

Relativity
Although, Albert Einstein (1879 – 1955) never met Boltzmann personally (the young Einstein was surely much too modest to seek a meeting with the celebrated man), all Einstein's early work was in the Boltzmann tradition. It is known that Einstein formulated the theory of relativity by inspiration from Maxwell's electroldynamics. On the other hand, historical consideration shows that most German-speaking physicists of that time learned Maxwell's theory from Boltzmann's writings. In addition, the Einstein's light quantum hypothesis suggesting that the energy of the light itself and not merely that of the absorber is quantized, which is another root of quantum physics, was proposed through application of the Boltzmann principle to the radiation field.

Note: Philosophical articles of Boltzmann have been collected in book editions, and thus, the individual articles are not addressed here.

Note: The quotations noted throughout this article were taken from Boltzmann's articles, which can be found in the books referenced (mainly *Theoretical Physics and Philosophical Problems*).

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